Step-down Rectifier using Modular Multilevel Converter for Wind Power Generation System connected to DC Micro-grid

Toshiki Nakanishi*a), Jun-ichi Itoh*

Abstract: This paper discusses a step-down rectifier which is constructed by a Modular Multilevel Converter (MMC) for a wind power generation system connected to a DC micro-grid. The proposed system which is constructed by the MMC with an H-bridge cell achieves to convert from a generator voltage of 3.3 kV into DC bus voltage of 340 V. Moreover, as a fundamental evaluation, the experimental results by miniature model of 700 W confirm that the proposed system achieves the step-down operation from the input voltage of 200 V into the DC voltage of 65 V. Finally, the proposed system maintains the capacitor voltage of each cell to the voltage command. Furthermore, the maximum voltage error between the voltage command of the cell capacitor and the measured voltage is 10% or less.

Keywords : Modular Multilevel Converter, H-bridge cell, DC micro-grid, Wind power generation system, High power rectifier

1. Introduction

Recently, a micro-grid and a DC power grid are actively researched as a next generation power supply[(1)-(2)]. Moreover, the DC micro-grid is suitable to connect a battery energy storage system and a renewable energy source such as a photovoltaic generation system and a fuel cell because the output voltage of many renewable energy sources is DC voltage. Thus, the micro-grid has been applied to the power grid in isolated islands as a stand-alone power system[(3)]. Additionally, a wind power generation is also applied to the power grid in isolated islands as one of the power source[(3)]. However, a size of the transformer in the wind power generation system is bulky because the transformer operates in low operation frequency of the generator. In addition, the reasons which the transformer is bulky include that a high transformer ratio is required to convert from generator voltage into DC bus voltage. On the other hand, the wind power generation system without the transformer by using a Modular Multilevel Converter (MMC) is an effective solution. However, in the general AC-DC converter using the MMC which consists of chopper cells[(4)], it is difficult to achieve the step-down rectification because chopper cells cannot output negative voltage.

This paper discusses a step-down rectifier using the MMC and the control system in order to convert from high voltage AC into low voltage DC. Moreover, from an experimental result by miniature model of 700 W, the proposed system achieves to convert from three phase voltage of 200 V into the DC voltage of 65 V.

2. Main Circuit Configuration

Fig. 1 shows the main circuit configuration of the proposed wind power generation system using the MMC. Each leg consists of two buffer reactors L_b and H-bridge cells. Due to cascade connection of cells, the converter achieves a multi-level voltage

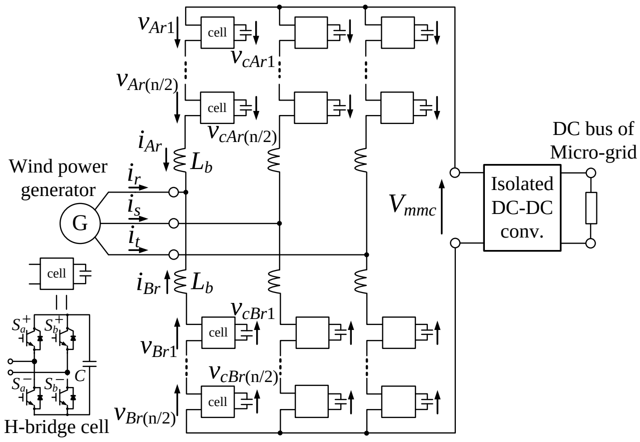

Fig. 1. Circuit configuration of the MMC for the wind power generation system connected to the micro-grid. The MMC with H-bridge cells is able to operate the step-down rectifier.

waveform and also reduces the rated voltage of each cell. Thus, many cascaded cells are used in practical because it reduces the harmonic distortion and utilizes low voltage rating devices. On the other hand, in the MMC, the output DC voltage depends on the summation of the average value of cell output voltage.

3. Control Strategy

Fig. 2 shows the control block diagram of the proposed step-down rectifier. The greatest feature of the proposed control system is to control each arm as shown in Fig. 1. Additionally, the control block diagram is separated to the capacitor voltage control block and the input current control block. Moreover, the capacitor voltage control block consists of a voltage averaging control system and a voltage balancing control system.

3.1 Voltage Averaging Control System The voltage averaging control system is applied in order to control the average value of all capacitor voltage in the arm. The error between the capacitor voltage command and the average value of capacitor voltage in the arm is corrected by a PI controller. Moreover, the

a) Correspondence to: Toshiki Nakanishi.
E-mail: nakanishi@stn.nagaokaut.ac.jp
* Nagaoka University of Technology
1603-1, Kamitomioka-machi, Nagaoka city, Niigata, Japan 940-2188

output value of the PI controller is given as the command of a positive phase current. Thus, the command of the positive phase current is generated depending on the fluctuation of the average value of all capacitor voltage in the arm.

3.2 Voltage Balancing Control System The voltage averaging control system is used to keep the voltage of all capacitor voltage. However, an unbalance voltage which occurs among capacitors in same arm cannot be suppressed by voltage averaging control system only, because the voltage averaging control system corrects only the error between the voltage command and the average value of the capacitors voltage in the arm. In addition, the positive phase current in order to keep the capacitor voltage flows to all cells which exist in 1 arm. Moreover, the common value of the positive phase current which flows each arm. Thus, it is difficult to adjust the arm current in order to balance on each cell. Against the problem, the output DC voltage of the cell is varied depending on the capacitor voltage. Thus, the output power of the cell is varied depending on the capacitor voltage. This control principle is given by equation (1).

$$V_{mmc\_mki}{}^{*} = \frac{1}{2}\frac{v_{cmki}}{\sum_{x=1}^{n/2} v_{cmkx}} V_{mmc}{}^{*} \quad \cdots\cdots (1)$$

where $V_{mmc\_mki}{}^{*}$ is the output DC voltage command of each cell. i is the index of the cell number. Moreover, m, k and i are matched in both side of equation (1).

4. Experimental Results

Table I shows the experiment condition of the prototype. In the prototype, the leg is constructed by four cells.

Fig. 3 shows waveforms of the input phase voltage, the input current and the output DC voltage. Firstly, from the waveforms of the input phase voltage and the input current, it is confirmed that the unity power factor is obtained in the input stage. Moreover, the total harmonic distortion (THD) of the input current is 6.5%. Thus, as a future work, it is necessary to reduce the total harmonic distortion of the input current.

Second, the waveform of the output DC voltage in lower side of Fig. 3 shows that the prototype converts from the input voltage of 200 V into the output DC voltage of 65 V. From this waveform, the output DC voltage is kept at constant. Therefore, the prototype of the MMC achieves the step-down rectification.

Fig. 4 shows the waveforms of the cell capacitor voltage which are connected to the r-phase leg. The cell capacitor voltage is controlled according to the capacitor voltage command $v_c{}^{*}$. As a result, the proposed system maintains the capacitor voltage of each H-bridge cell to the voltage command of 120 V. Furthermore, the maximum voltage error between the voltage command of the cell capacitor and the measured voltage is 10% or less. As a future work, it is necessary to consider the cause of the error between the voltage command and the measured voltage.

5. Conclusion

This paper discusses the step-down rectifier using a modular multilevel converter (MMC) for the wind power generation system without the bulky transformer connected to the DC micro-grid. Moreover, the proposed control system is very simple because the control system is applied to the each arm of the MMC. From the experiment result, the proposed control maintains the capacitor voltage at constant. In the future work, the method to reduce of the THD of the input current and will be discussed.

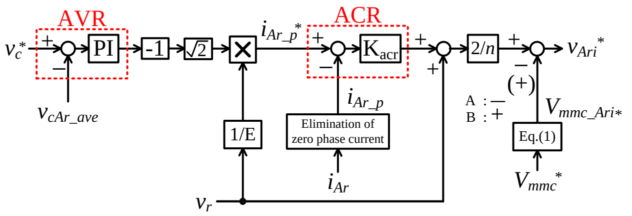

Fig. 2. Control block diagram for step-down rectification of MMC. The control system is applied to each arm of the MMC.

Table 1. Experimental conditions.

Input voltage rms E	200 V	Output power P_O	700 W
Input voltage frequency f	50 Hz	Buffer reactor L_b	4 mH (&Z=1.09%)
Number of cell per leg n	4	DC capacitor C	1,300 μF
Carrier frequency f_S	8 kHz	Load R	5.8 Ω

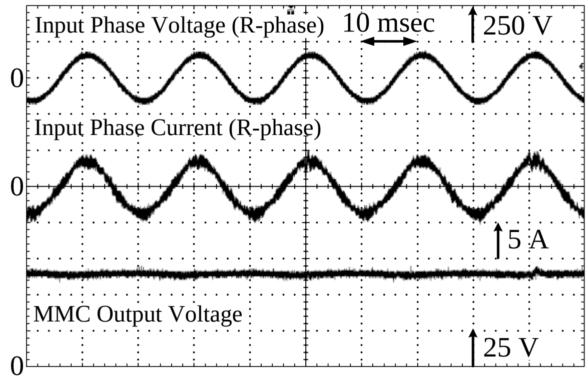

Fig. 3. Waveforms of input voltage, input current and output voltage. The unity power factor is be obtained in the input stage. On the other hand, the THD of the input current is 6.5%.

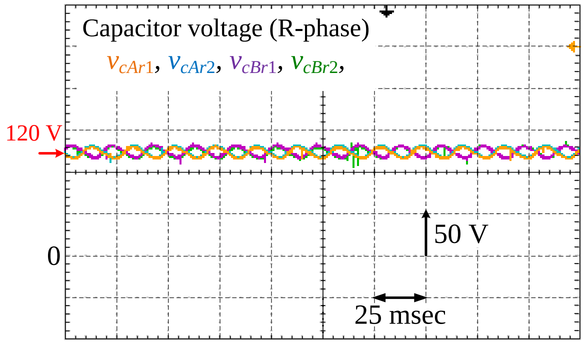

Fig. 4. Waveforms of the capacitor voltage in r-phase leg. The proposed system maintains the capacitor voltage of each H-bridge cell to the voltage command of 120 V. The maximum voltage error between the voltage command of the cell capacitor and the measured voltage is 10% or less.

References

(1) H. Kakigano, Y. Miura, and T. Ise, "Low-Voltage Bipolar-Type DC Microgrid for Super High Quality Distribution," IEEE Trans. on Power Electronics, Vol.25, No.12, pp.3066-3075 (2010)

(2) N. Hatziargyriou, H. Asano, R. Iravani, C. Marray, "Microgrids," IEEE Power and Energy Magazine, Vol.5, No.4, pp.78-94 (2007)

(3) T. Senju, T. Nakaji, K. Uezato, and T. Funabashi, "A Hybrid Power System Using Alternative Energy Facilities in Isolated Island," IEEE Trans. on Energy conversion, Vol.20, No.2, pp.406-414 (2005)

(4) M. Hagiwara, K. Nishimura, H. Akagi : "A Medium-Voltage Motor Drive With a Modular Multilevel PWM Inverter", IEEE Transactions on Power Electronics, Vol.25, No.7, pp.1786-1799 (2010)